

ALPS: yield optimization cutting program

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Abstract

This paper reports ongoing work on a series of computer programs developed to automate hardwood lumber processing in a furniture roughmill. The program computes the placement of cuttings on lumber, based on a description of each board in terms of shape and defect location, and a cutting bill. These results are suitable for use with a high-power laser to cut the parts from the lumber. The placement algorithm employed is based on a heuristic approach that provides simplicity and short computation time. In its present form, the program is intended to be used as a research tool for further investigation of an Automated Lumber Processing System (10) that, in addition, incorporates computer vision to grade and locate defects in lumber.

At present, the computer is used primarily to perform tasks that require little in the way of innate intelligence. Computers used in the hardwood industry primarily direct computer numerical control (CNC) machines in much the same way a human worker would, by manually moving the workpiece and changing tools (9). Future advances in automating wood processing will require that the computer be incorporated into the decision making process. In fact, incorporating computers will require that new techniques be developed to take full advantage of the computer's unique capabilities. A case in point is the Automated Lumber Processing System (ALPS) proposed by McMillin et al. (10). This approach seems to be one alternative for many hardwood processors to remain competitive in the face of dwindling quality resources and increased foreign competition (1).

The ALPS system uses computers in a unique way to completely redefine the way in which wood parts are produced. The system consists of four components:

1. A computer vision system to locate and identify defects on the lumber surface;
2. A computer program to assign National Hardwood Lumber Association grades (11) to lumber;
3. A yield optimization cutting program to compute an efficient cutting strategy;
4. A cutting system that uses a high-power laser to cut parts from the lumber.

The advantages of such a system are numerous. Using the computer to identify defects and determine the placement of cuttings will significantly reduce waste from operator fatigue and inexperience. Using a laser to produce cuttings introduces a new technique that promises to produce greater cutting yields. Rather than being restricted to using a series of rips and crosscuts, the laser can be used to cut pieces of arbitrary shape from any position on the board, much like a cookie cutter. This "punch cut" method requires that cutting placement decisions be made with great consideration in order to maximize yield. An added advantage associated with using a laser is the narrow kerf (-0.025 in.) that results from this type of cut.

Preliminary work regarding the feasibility of the ALPS system indicates promising results. A financial analysis of a processing system using computer vision and lasers shows the process to be economically attractive (4,6). The development of a prototype system for defect detection using image processing techniques is

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currently underway. Results of this effort have already been reported (2,5,8). A computer program for grading hardwood lumber has recently been written by the authors and is intended to be incorporated into the ALPS system (7).

The ALPS yield optimization cutting program

The program described here implements the third of the four parts of the ALPS system just described, the cutting placement program. The program accepts board data using a format compatible with the output of a computer vision system. In its present form, the program is intended to be used as a research tool for further investigation of this novel processing technology. The program currently runs on IBM PCs and compatibles. In the near future, the core of the program will be incorporated directly into the software of a processing system that will use laser and computer vision technology.

Using the program

The program provides the user with three processing choices. One option allows the user to manually enter data that describes boards: dimensions and the location, size, and types of defects. The second option allows the user to create a cutting bill. When creating a cutting bill, users enter the dimensions of a cutting, along with the required quantity and respective numerical weight assigned to the piece. The weight is used by the placement algorithm to discriminate among various placement strategies. The data describing both boards and cutting bills can be saved in data files for future use. The third option performs the actual cutting placement. As the program processes each board, a graphic display of the cutting placement can be shown on the monitor. The user has the option of creating a hardcopy image of the placement with either a pen plotter or dot matrix printer. Statistical information gathered during processing is stored in a disk file for future reference.

Algorithm development

A heuristic placement algorithm was developed for the ALPS cutting program in lieu of an optimal one. The primary reason for this is due to the ill-defined nature of the placement problem i.e., what exactly constitutes an "optimal" placement? Such a placement should be capable of being expressed in a formal and mathematically precise manner. Intermediate results of our research indicate that maximizing yield (expressed as the percentage of clear area available) is not the same as maximizing value. Further complicating the situation is the nature of the material itself. Lumber is far from being a uniform, blemish-free product. The dimensions and the number and locations of defects occur in a random and unpredictable fashion. The preceding factors were sufficient inducement for the development of a heuristic placement algorithm. Specifications for such an algorithm were that it be robust, and that it demonstrably indicate a consistently better yield, no matter how defined, than other competing algorithms.

Sixteen different placement strategies were considered and computer programs written for each. Each of the 16 algorithms first locate all rectangular areas that are at least as large as the smallest cutting on the cutting

bill. Once these areas are found, they can be processed in several different ways. The algorithms differ in the way that these areas are processed. There are three different areas in the optimization process that were altered for each of the algorithms. The three different areas and the possible variations used for each are as follows:

1. Choice of which clear area cuttings will be placed in first. Seven possibilities were tested in this case:

a. Choose the clear area that has the most overlap into adjacent clear areas.

b. Choose the clear area that lies closest to the bottom edge of the board. If more than one such area exists, choose the area that lies closest to the left edge of the board.

c. Choose the clear area that has the most area.

d. Choose the clear area that lies closest to the left edge of the board. If more than one such area exists, choose the area that lies closest to the bottom edge of the board.

e. Choose the clear area that lies closest to the left edge of the board. If more than one such area exists, choose the area that is longest.

f. Choose the clear area that lies closest to the left edge of the board. If more than one such area exists, choose the area that has the most area.

g. Choose the clear area that lies closest to the left edge of the board. If more than one such area exists, choose the one that has the greatest product resulting from multiplying the square of the length of the area by its width.

2. Choice of how the cuttings will be placed in the block of clear area. Two possibilities were tested in this case:

a. For each size on the cutting bill, determine the number of pieces that will span the length and width of the clear area. Multiply the number of pieces by the weight assigned to the piece. The cutting size that yields the greatest value will be chosen.

b. For each piece on the cutting bill, place only one piece that yields the greatest returned value.

3. Placement of cutting blocks in clear area. Three possibilities exist in this case:

a. Place the entire block of cuttings in the lower left corner of the clear area.

b. Determine the centroid of the clear area with respect to the length and width of the board. If the centroid with respect to the length falls to the left of the center of the board, shift the block to the left edge of the clear area. Otherwise, shift the block to the right edge. If the centroid with respect to the width falls above the center line of the board, shift the block to the upper edge of the clear area. Otherwise, shift the block to the lower edge of the area.

c. Determine the centroid of the clear area only with respect to the width of the board. If the centroid with respect to the width falls above the center line of the board, shift the block to the upper edge of the clear area. Otherwise place the block against the lower edge of the clear area. The block of cuttings is always placed against the left edge of the clear area in this case.

Table 1 shows which permutations of the possibilities just described were used for each of the 16 algo-

TABLE 1. — Features used in each of the sixteen algorithms tested and resulting yields from each.

Algorithm	Features	Cutting bill			
		Bill 1	Bill 2	Bill 3	Bill 4
		(%)			
A	1b,2a,3a	68.12	69.28	75.56	79.26
B	1d,2a,3a	66.81	68.99	74.30	78.22
C	1e,2a,3a	68.95	69.61	76.24	79.16
D	1f,2a,3a	66.06	68.39	74.48	77.91
E	1e,2a,3c	70.48	70.97	76.71	80.41
F	1f,2a,3c	68.11	69.92	75.08	79.04
G	1a,2a,3b	68.34	69.24	76.28	77.75
H	1c,2a,3b	67.51	69.78	75.98	77.80
I	1a,2b,3a	65.41	66.11	71.37	73.45
J	1a,2b,3b	66.57	67.77	71.84	74.65
K	1a,2b,3c	66.02	66.86	71.99	74.15
L	1c,2b,3a	65.87	68.08	71.81	73.79
M	1c,2b,3b	67.35	69.08	72.45	74.87
N	1c,2b,3c	67.12	68.61	72.63	74.60
O	1e,2b,3c	72.18	70.75	73.66	79.16
P	1f,2b,3c	70.57	71.02	72.03	76.89

TABLE 2. — Cutting bills.

Length (in.)	Width (in.)	No. of pieces
Cutting bill no. 1		
15 1/2	7 1/4	200
21	2 3/4	400
58	5	200
20 1/2	2	1,200
21	4	1,200
18 1/2	8	400
Cutting bill no. 2		
44 5/8	2 1/8	206
18 1/4	1 5/8	130
45	2	260
59	2	515
22 3/4	4 7/8	206
53 1/2	2 3/4	206
Cutting bill no. 3		
80 1/2	1 3/4	420
20 3/4	5/8	106
20 5/8	1 3/4	420
26 1/2	2 3/8	210
22 1/2	2 3/8	210
Cutting bill no. 4		
71 1/4	1 3/4	9,363
30 1/2	6	9,384
28 3/4	8 7/8	9,557
28 3/4	6 1/4	9,694
28 3/4	2 5/8	9,329
27 3/4	1 1/4	9,320
27	2 5/8	9,132
27	2 1/2	9,100
24	3 1/2	9,227
24	1 1/2	9,865
21	2 1/8	9,102
18	3 1/4	9,444
18	2	9,900
15	15	9,533
15	1 3/4	9,900

gorithms. Data were collected for each algorithm based on the simulated processing of 100 No. 1 and No. 2 Common boards using the four cutting bills shown in Table 2. The percent of total area recovered is also shown in Table 1. The selected algorithm was chosen empirically, based on a comparison of the yields. Figure 1 shows the percentage of clear face area recovered in cuttings for the five best algorithms. Yields, when measured in this manner, are comparable from one method to the next.

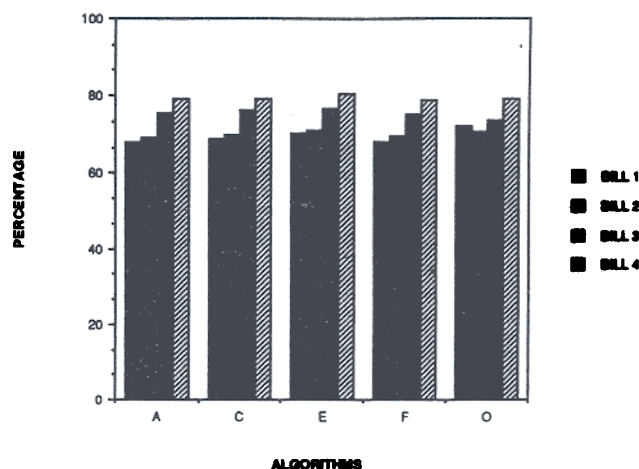


Figure 1. — Comparison of clear area returned.

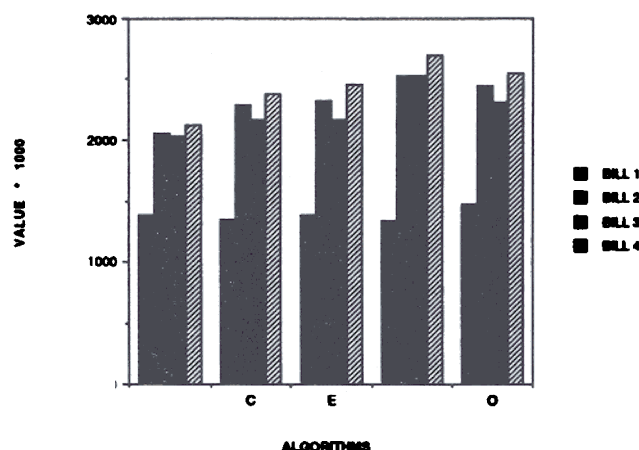


Figure 2. — Comparison of value returned.

Assigning weights not according to area, but with some more realistic measure, was then tested. In this case, the weight of each cutting was determined by the product of the square of its length and its width. The results from this test are shown in Figure 2, which clearly indicates that one algorithm is superior to the others when using this more realistic measure.

The placement algorithm

The placement algorithm relies on the fact that lumber is typically many times longer than it is wide. Thus, the utilization of clear area in one region of the board is frequently independent from another. This factor allows utilization of localized regions to be optimized, with the hope that overall, the placement is near-optimal.

The algorithm consists of four iterative steps. The first step searches the board for clear areas. These areas are rectangular regions bounded by either defects or board edges. Each clear area found must be as large as the smallest of all pieces on the cutting bill. From among the areas found in step one, the algorithm then selects one. This area is selected based on its distance from the left end of the board. The area whose left edge lies closest

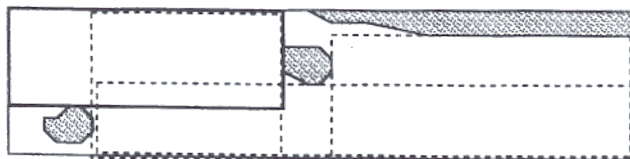


Figure 3. — Clear areas available (dotted lines) and the selected clear area (dark lines).

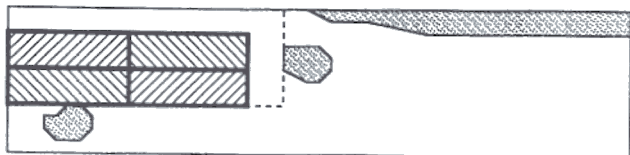


Figure 4. — Local optimization in the selected clear area.

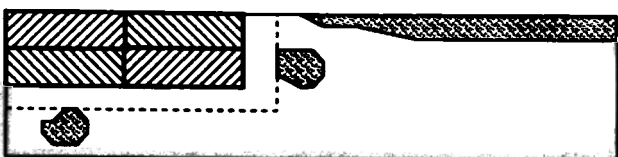


Figure 5. — Final placement of the cut in the selected area.

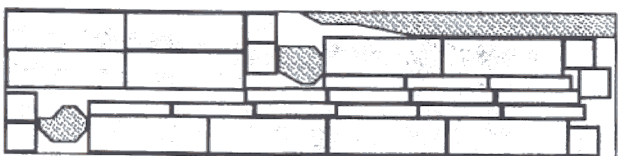


Figure 6. — Overall final placement.

to the left end of the board is chosen. Arbitration takes place if more than one area satisfies this criteria. Shown in Figure 3 are a number of clear areas. The clear area selected by step 2 is shown in thick solid lines.

With the clear area chosen, the third step optimizes the placement of cuttings within that area. Optimization is constrained by the requirement that only one cutting size can be placed into the area, and only in a rectangular block formation. The particular size chosen is the one that maximizes the yield from among all the different sizes of cuttings. Yield is calculated as the number of pieces so placed, multiplied by the size's numerical weight. The process can be considered as "local optimization" over a restricted region of the board. At the conclusion of the third step, the rectangular block of cuttings is placed in the lower half of the clear area against the end closest to the left end of the board, as illustrated in Figure 4. The final step of the algorithm determines the ultimate placement of the cuttings within the clear area. It is unlikely that the block fills the entire area; some margin of clear area still remains. The placement of the block is then adjusted to allow the mar-

gin to be utilized to its best potential in the next iteration. Figure 5 typifies the movement to allow better future utilization. Having determined the final location of the block, it is then marked as a "defect." The iterations are then repeated until no further clear areas exist that are larger than the smallest available pieces in the cutting bill. Figure 6 shows the overall final placement.

Conclusion

Preliminary tests of the ALPS algorithm have provided encouraging results. The algorithm results show a substantially better yield than the table for conventional processing (3). Work is currently underway to enhance and improve the cutting placement algorithm. One limitation of the current algorithm is that it is restricted to rectangular cuttings. ALPS project members are currently evaluating an improved method that will allow the placement of irregularly shaped parts. Other research underway includes studies to develop better methods of assigning weights and minimizing the travel of a laser when cutting parts from lumber.

The software runs on IBM PC or compatible machines. Requests for information on how to obtain the software should be directed to Dr. C.W. McMillin, Southern Forest Experiment Station, 2500 Shreveport Highway, Pineville, LA 71360.

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